Thursday, January 12, 2016

7:00 - 8:00 Breakfast

Distribution Controls, Markets, and Human in the Loop Response

8:00 - 8:30 Ian Hiskens, University of Michigan; *Modelling and Control of Load Ensembles*

Participation in fast-acting demand response can be maximized through aggregation of many small electrical loads. Numerous control strategies have been proposed for coordinating the behaviour of load ensembles to assist in power system operations. Modelling the natural and controlled response of such distributed systems is, however, quite challenging. A variety of modelling formalisms have been developed, with the presentation providing an overview and discussion of their characteristics. The dynamic behaviour of load ensembles is strongly dependent on stochasticity and disorder within the load population. These effects will be illustrated and methods of capturing uncertainty within aggregate models will be considered. Load ensembles are inherently nonlinear and may display quite complicated dynamics, for example bifurcations arising from synchronization. Accordingly, controls must be carefully designed to avoid such situations. The presentation will consider various control strategies that have been proposed for enabling load ensembles to support grid operations. System response will be illustrated using simple case studies.

8:30 – 9:00 Daniel Kirschen, University of Washington; *Operating and Planning Battery Energy Storage in a Competitive Market Environment*

9:00 - 9:30 Steven Low, Caltech; *Online Optimal Power Flow*

The optimal power flow (OPF) problem underlies numerous power system operation and planning applications. Traditional OPF algorithms are offline in that they solve power flow equations explicitly or implicitly, and iteratively until the computation converges before applying the final solution. This is computationally challenging because power flow equations are nonlinear. The grid however implicitly solves power flow equations in real-time at scale for free. We propose to explicitly exploits the network as a power flow solver to carry out part of our optimization. This approach naturally adapts to evolving network conditions. Specifically, we present an algorithm that adapts controllable devices and interacts continuously with the grid which computes a power flow solution given a control action. Collectively these devices and the grid implement a gradient or Newton-like algorithm in real time. We characterize optimality and tracking properties of the online algorithms, and present simulation results to illustrate their effectiveness.

9:30 - 10:00 Coffee Break

10:00 - 10:30 Line Roald, Los Alamos National Laboratory; *Chance-constrained AC Optimal Power Flow*

Uncertainty and risk in transmission system operation is increasing due to the increasing share of renewable electricity generation. To ensure secure and economically efficient system operation, methods for operational planning such as the optimal power flow (OPF) should be extended to both assess and mitigate this risk. Targeting this objective, we suggest formulating the OPF as a stochastic optimization problem using chance constraints, which limit the risk of generation and transmission overloads to below a defined threshold. Previous formulations of chance-constrained OPF have mostly focused on the linear DC power flow formulation, which makes the problem easier to solve, but yields less accurate solutions. In this talk, we present a method to solve the chance-constrained AC OPF based on a partial linearization and an analytical chance-constraint reformulation. We further discuss an iterative solution procedure, and compare the performance of the analytical reformulations with two sample based methods.

10:30 - 11:00 Emiliano Dall'Anese, National Renewable Energy Laboratory; *A system-theoretic control framework for virtual power plants*

Traditional approaches for regulating and maintaining system frequency in power transmission systems leverage primary frequency response, automatic generation control (AGC), and regulation services provided by synchronous generators. In the future, on the other hand, distributed energy resources (DERs) at both utility level and in commercial/residential settings are envisioned to complement traditional generation-side capabilities at multiple time scales to aid frequency regulation and maintaining a reliable system operation. Aligned with this emerging vision, this talk considers a distribution system featuring DERs, and presents a system-theoretic control strategy for DERs that enables a distribution feeder to emulate a virtual power plant effectively providing services to the main grid at multiple temporal scales. By cross-fertilizing feedback control with time-varying optimization theory, we design a real-time feedback control strategy for DERs that enable the active and reactive power at the feeder head to track given setpoints (e.g, dispatch, ramp, or AGC signals), while concurrently ensuring that electrical quantities are within given limits throughout the feeder. The design of the feedback controllers is grounded on suitable linear approximations of the AC power-flow equations, and leverages online primal-dual gradient methods applied to pertinent minimax problems encapsulating the controllers objectives.

11:00 - 12:00 Contributed Talks TBD

12:00 - 1:30 Lunch

Machine Learning and Probabilistic Methods

1:30 - 2:00 Daniel Bienstock, National Columbia University; *Robust policies for storage used to offset renewable variance*

We describe a class of multistage optimization models used to plan storage operation in order to offset deviations from renewable output forecasts. These are OPF-like models where policy computation takes place at time zero, and at time t = 1, 2,... T storage operation is revised using a linear policy. We assume that renewable output deviations are estimated from measurements; errors in forecast and in measurement are handled using robust constraint modeling. The constraints we consider are line limits, and, especially, battery capacity limits. A notable detail is that due to differing charging and discharging battery efficiencies, battery operation is described using a nonconvex model (as has been noted by other authors). However, our cutting-plane algorithm is able to efficiently separate from this set.

In this talk we focus on several issues: (1) scalability of the algorithm to grids with thousands of buses and lines, (2) impact of the robust data model, and (3) impact of using 'attribution' storage operation policies, whereby a given storage unit is used to respond to a selected subset of renewable locations only.

2:00 - 2:30 Dejan Sobajic, Grid Consulting LLC; *Power System Control Using Neural Networks*

This presentation is discussing research activities in a domain of artificial neural networks based control of power systems. Research has been carried out at Case Western Reserve University in Cleveland OH and Stanford University in California in the period between 1990 & 1996. Power system control problems will include load-frequency control and generator excitation control. Neural network research has been focused on supervised and unsupervised learning systems, functional link enhancements and a concept of backpropagation in time. Numerical results obtained in digital simulations will be provided.

2:30 - 3:00 Deepjyoti Deka, Los Alamos National Laboratory; *Topology Learning in Power Grids from Ambient Fluctuations*

Distribution Networks provide the final tier in the transfer of electricity from generators to the end consumers. There has been a recent surge in the deployment of nodal smart meters in distribution networks for use in demand response, improved home-monitoring and other smart grid inspired topics. We discuss learning and estimation problems in the distribution grid using available nodal voltage and phase data in two regimes: static and dynamic.

In the static regime, our learning algorithm relates to general graphical model learning and uses the power flow equations. In the dynamic setting, we demonstrate the use of Wiener filter based reconstruction of the operational topology from the swing equations of frequency fluctuations. In particular, we show the technical and practical advantage of using dynamic reconstruction over the static case for loopy networks.

This work can be applied to improve control and optimize operations in the grid as well as to understand the scope of adversarial attacks on grid security.

3:00 - 3:30 Coffee Break

3:30 - 4:00 Kaarthik Sundar, Los Alamos National Laboratory; *Probabilistic N-k Vulnerability Analysis for Power Systems*

Extreme events, either natural (viz. super-storm Sandy, hurricane Matthew, blackouts) or man-made (viz. cyber attacks), pose a major threat to the nation's electric grid and the socio-economic systems that depend on reliable delivery of power. They enforce the need to develop effective computational tools for discovering vulnerabilities and identifying critical components of the electric power transmission grid.

The N-k problem focuses on identifying an N-k contingency i.e., a set of k critical components of the transmission system, whose simultaneous or near-simultaneous failure would maximize the disruption, measured in terms of the amount of load shedding caused by this failure, to the customers of the grid. We shall discuss a probabilistic version of the N-k problem in transmission systems, where the probability of failure of each component in the network is known a priori and the objective of the problem is to find a set of k components that maximizes the likely minimum load shed in the system. The resulting problem is formulated as a bi-level Mixed-Integer Second Order Cone Program and a decomposition algorithm is developed to solve the formulation; the sub-problems in the decomposition algorithm incorporate a convex relaxation of the AC power flow equations. We shall present preliminary computational results corroborating the effectiveness of the algorithms on IEEE RTS96 three area system.

4:00 - 4:30 Baosen Zhang, University of Washington; *An Optimal Treatment Assignment Strategy to Evaluate Demand Response Effect*

6:30 - 9:00 Conference Banquet Dinner

Friday, January 13, 2016

7:30 - 9:00 Breakfast

Emergency Controls, Protection, Risk, Extreme Events

9:00 - 9:30 Krishnamurthy Dvijotham, Pacific Northwest National Laboratory; *Inner feasible approximations and robust optimization for infrastructure systems*

Infrastructure networks like gas and power grids deliver critical services and need to be operated with a high degree of reliability. However, these networks are subject to growing amounts of uncertainty due to intermittent renewable generation sources, uncertainty in flexible demand resources and interdependence between networks. Further, analyzing the behavior of these networks is complicated because of the nonlinear nature of the equations describing the steady-state behavior. In recent years, we have developed novel techniques for "inner feasible" approximations of nonconvex sets that describe allowable operating points for infrastructure systems. We analyze the tightness of these characterizations, and describe applications of these techniques for robust optimization in infrastructure networks. This is the first general approach for robust nonconvex optimization problems with feasibility guarantees.

This is joint work with Konstantin Turitysn, Hung Nguyen, Suhyoun Yu, Enrique Mallada and John Simpson-Porco.

9:30 - 10:00 Bernie Lesieutre, University of Wisconsin-Madison; *Enumerating Solutions to the Optimal Power Flow Problem*

The traditional power flow problem computes network voltages consistent with a specified pattern of power injections, and it is known to exhibit multiple solutions. Likewise, the optimal power flow problem that computes least-cost generator dispatches is nonconvex and exhibits multiple local minima. We present our work on enumerating local minima solutions. We expand on our previous work of representing the power flow equations in elliptical form and tracing between solutions. Specifically we construct an elliptical representation of the optimal sphere-constrained Fritz John conditions, and similarly trace between solutions that represent critical points of the OPF. We show that this method can trace between parts of a disjoint feasible space and we demonstrate that it can find multiple minima including the global optimum for some difficult cases when an SDP relaxation fails.

10:00 - 10:30 Mallikarjuna Vallem, Pacific Northwest National Laboratory; *Dynamic Contingency Analysis Tool (DCAT) – A framework for analysis of extreme events in power systems*

The Dynamic Contingency Analysis Tool (DCAT) is a software package developed by researchers at PNNL in partnership with the DOE Office of Electricity Delivery and Energy Reliability and Electric Reliability Council of Texas (ERCOT). The bulk electric power grid is subject to vulnerabilities from component outages, which in certain combinations (extreme events) might lead to cascading outages. Much is known about avoiding the first few failures near the beginning of a cascade, but there is a deficit of established methods for directly analyzing the risks and consequences of the cascading component outages over a longer time scale. DCAT is an open-platform and publicly available methodology to help develop applications that aims to improve the capabilities of power system planning engineers to assess the impact and consequences of extreme contingencies and potential cascading events across their systems and interconnections. Outputs from the DCAT will help find mitigation solutions to reduce the risk of cascading outages in technically sound and effective ways. This presentation will provide details of DCAT methodology and shows its implementation with some extreme events on real world utility cases which show a marked difference from what are visualized with the existing power system planning tools.

10:30 - 11:00 Coffee Break

11:00 - 11:30 Sidhant Misra, Los Alamos National Laboratory; *Corrective control for system security*

Corrective control refers to control actions employed by the system operator to ensure system feasibility following a contingency or uncertain deviation from forecasted load or generation. Traditionally, the corrective controls were usually sufficient to cover all probable ?emergency? scenarios. However, the power system today is more complex, faces significantly more uncertainty, and is operated much closer to its limit. Thus, the available control actions are becoming increasingly insufficient to ensure feasibility. To avoid costly emergency actions such as load shedding, it now becomes necessary to plan for the availability of corrective control during the operational planning stage itself. Towards this goal, we propose to employ an adjustable robust/chance constrained optimization framework by including a representation of the control action policies in the operation planning optimization problem. The resulting nominal operating point is marginally more expensive but much more secure, since it guarantees the existence of inexpensive and effective control actions for all probable emergency scenarios.

11:30 - 12:00 Arkadiy Landman, Power System Automation Institute; *Up to date elaboration trends of anti-fault control systems of integrated grid systems*

12:00 - 1:30 Lunch

Network Design, Planning, and Optimization

1:30 - 2:00 Andy Sun, Georgia Institute of Technology; *Strong convex relaxations and global optimization for AC optimal power flow*

2:00 - 2:30 Pascal van Hentenryck, University of Michigan; *Convexification of Stead-State Equations*

This talk reviews some recent results in the complexity and convexification of the steady state equations for electricity and gas networks. It covers both theoretical results, computational experiments, and their application in a number of challenging problems.

2:30 - 3:00 Mikhail Davidson, MSU, Scoltech, Carana; *Regularization of the Newton-Raphson method for minimizing squared norm of the error of the load flow equations*

3:00 - 3:30 Coffee Break

3:30 - 4:00 Dan Molzahn, Argonne National Laboratory; *Error Bounds on Power Flow Linearizations: A Convex Relaxation Approach*

4:00 - 4:30 Scott Backhaus, Los Alamos National Laboratory; *Probabilistic Risk Analysis of Hurricane Impacts at Distribution Network Resolution*

Wind damage to electrical distribution systems are a major cause of long-term electric outages from hurricanes. The risk of long-term outages depends on both the rate of future major hurricane events and the natural evolution of distribution system resilience driven by past hurricane events. These factors can make the risk long-term outages very inhomogeneous across a distribution grid, however, the low spatial resolution of typical electric power outage and restoration forecasting models used in hurricane impact studies is inadequate for assessing facility-specific risk of long-term electrical power outages. High spatial resolution outage and restoration models are described, and a preliminary implementation of the models and results from probabilistic risk analysis (PRA) using this model are discussed. The PRA results show the current resilience posture of one electrical distribution utility and the effectiveness of different resilience upgrade policies.